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The Wind Atlas Methodology – Revisited

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Since the publication of the Wind Atlas for Denmark almost 30 years ago, the wind atlas methodology has had a significant impact on wind resource assessment and siting of wind turbines and wind farms all over the world. Major milestones are the Wind Atlas for Denmark (1979), the European Wind Atlas (1989), the Wind Resource Atlas for Denmark (1999) and the Wind Atlas for Egypt (2005). Whereas the former three were based on observations of either atmospheric pressure or surface winds at a limited number of meteorological stations, the latter incorporates mesoscale modelling based on comprehensive reanalysis data.

In addition, the wind atlas methodology – through its ability to transfer an observed wind climate from one location to a predicted wind climate at another nearby location – has been used to estimate the annual energy production of wind turbines and wind farms in well over 100 countries.

From this 30-year continuous research effort, a comprehensive and coherent wind atlas methodology has emerged, which can provide the data needed for physical planning, wind farm siting, project development, wind farm layout design, micro-siting and wind farm performance verification.

The current wind atlas methodology combines measurements, microscale modelling and mesoscale modelling to obtain a verified and reliable wind atlas for a region or country of any size. The main elements of the methodology are shown in schematic form in Figure 1.

MEASUREMENTS

A number of high-quality and well-distributed wind measurement stations are still needed to validate the model results for a given geographical area. A chain of carefully executed and well documented activities are needed to provide these locally measured data. The same careful approach is needed regarding the use and interpretation of externally measured wind data. In general, the use of existing meteorological stations only is not sufficient to ensure the quality and reliability of the wind atlas; some dedicated stations with tall masts (> 50 m) must usually be installed and operated at characteristic sites for verification.

Mesoscale	**Pre-processing** Wind classes Terrain elevation Terrain roughness Input specifications Model setup	**Modelling** Mesoscale model; e.g. KAMM, WRF, MC2, MM5 or similar.	**Post-processing** Predicted wind climate Regional wind climate Predicted wind resource for selected terrain site coordinates	**Numerical WA** Mesoscale maps Database of results WAsP *.LIB files Uncertainties Parameters
Measurements	**Met. stations** Siting Design Construction Installation Operation	**Wind data** Data collection Quality control Wind database Wind statistics Observed wind climate	**Verification** Meso- and microscale results vs. measured data Adjust model and model parameters to fit data Satellite imagery (offshore sites only)	**Applications** Best practices Courses and training Microscale flow model Wind farm wake model ⇒ **Wind farm AEP**
Microscale	**Pre-processing** Wind speed distributions Wind direction distribution Terrain elevation Terrain roughness Sheltering obstacles	**Modelling** Microscale model: Linearised, e.g. WAsP, MS-Micro or similar. Non-linear, e.g. CFD (Computational Fluid Dynamics).	**Post-processing** Regional wind climate Predicted wind climate Predicted wind resource for selected terrain site coordinates	**Observational WA** Microscale maps Database of results WAsP *.LIB files Uncertainties Parameters © 2006-08 Risø DTU

Figure 1: Schematic presentation of the current wind atlas methodology of Risø DTU

MICROSCALE MODELLING – OBSERVATIONAL WIND ATLAS

After pre-processing, the wind measurements are used as input to a microscale model which is able to model the influence of the nearby terrain on the measurements. Employing detailed descriptions of terrain elevation, land-use and the occurrence of sheltering obstacles around each meteorological station, the observed wind climate is transformed into what would have been measured at the location of the station if the surroundings were completely flat and uniform with a homogeneous surface, and the wind measurements had been taken at certain standard heights. Through this transformation procedure, the observed wind climate is freed from the influence of local topography to become regionally representative.

MESOSCALE MODELLING – NUMERICAL WIND ATLAS

Numerical wind atlas methodologies have been devised to solve the issue of insufficient wind measurements, which render wind resource mapping efforts through observational methodologies problematic. One such methodology is the

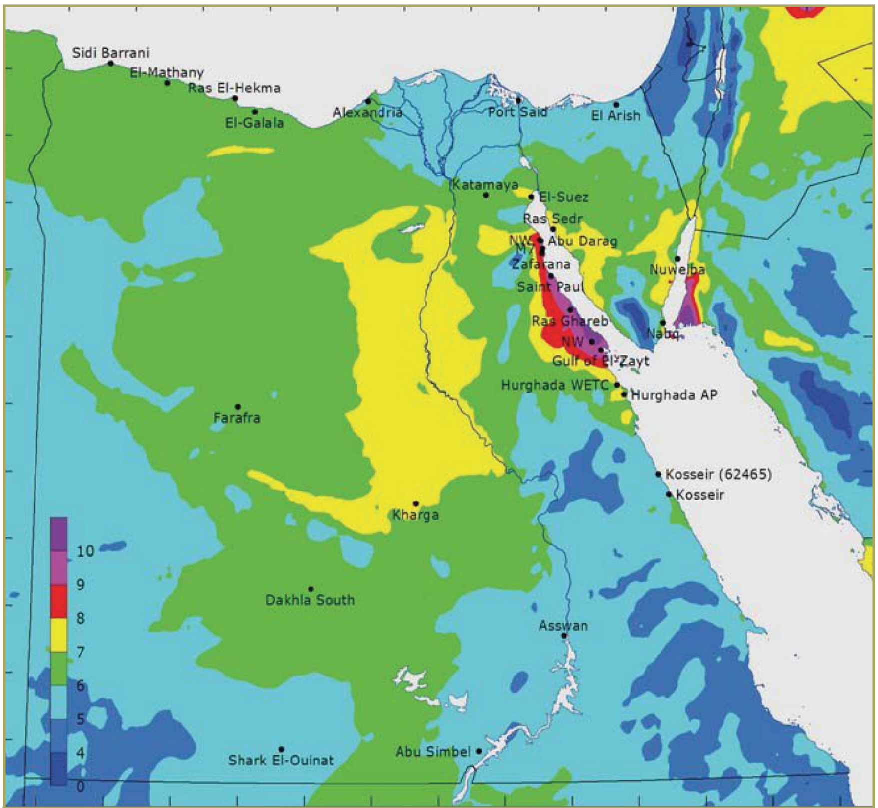

Figure 2: The regional wind climate of Egypt, shown here as the mean wind speed at 50 metres above ground level. The Wind Atlas for Egypt (2005) is available from the New and Renewable Energy Authority in Cairo, Egypt.

KAMM/WAsP method developed at Risø National Laboratory, now Risø DTU. In this methodology, an approach called statistical-dynamical downscaling is used. The basis for the method is that there is a robust relationship between meteorological situations at the large-scale and meteorological situations at the small-scale.

Information about the large-scale meteorological situation is available from the global NCEP/NCAR reanalysis dataset. Typically, a 30-year period of NCEP/NCAR data is used in the pre-processing stage to create approximately 150 different large-scale wind situations, called wind classes, that represent the large-scale wind climate. For each wind class a mesoscale model simulation is performed in order to find out how the large-scale wind forcing is modified by regional scale topography. Typically, the domain size is 500 km x 500 km in the horizontal and 6 km in the vertical. Finally, the mesoscale modelling results are combined to give the predicted wind climates at the grid points of the model.

The result of the mesoscale modelling is estimates of the wind climate in the 'mesoscale world'. These results are impacted significantly by the spatial resolution of the model, even at high resolutions, and therefore cannot be compared directly to measurements. The necessary step is to transform the model winds to certain standard conditions to account for the effects of the land-use and elevation differences as represented in the mesoscale model. Through the post-processing transformation procedures, the model winds are freed from the influences of the model topography to become regionally representative.

Figure 2 shows the regional wind climate of Egypt. It is based on predictions at more than 50,000 model grid points, which have been processed to obtain the regional wind climate at each point. Each grid point may therefore be thought of as a 'virtual meteorological station'. Place names indicate meteorological stations used for verification.

The numerical wind atlas methodology is in the process of being generalised to provide a systematic and flexible framework that can accommodate different mesoscale models.

VERIFICATION

Accounting for the topographical effects on the flow is the backbone of the wind atlas methodology. In the observational wind atlas, the observed wind climates are transformed into regional wind climates at each meteorological station. In the numerical wind atlas, the modelled (predicted) wind climates are transformed also into regional wind climates, but for each model grid point. In the verification process, only (regional) wind climates transformed to these standard conditions are compared, i.e. winds at standard heights over flat terrain

	National planning	Regional planning	Wind farm siting	Wind farm layout and micro-siting
Model type	Mesoscale	Mesoscale	Meso + microscale	Meso + microscale
Domain size	≈ 500-1000 km	≈ 100-500 km	≈ 20-100 km	10-20 km
Map resolution	5-10 km	1-5 km	10-100 m	1-10 m
Wind data	NCEP/NCAR reanalysis data	NCEP/NCAR reanalysis data	NCEP/NCAR + met. stations	Dedicated met. stations
Verification	Existing met. stations	Existing met. stations	Dedicated met. stations	Dedicated met. stations
Uncertainty on mean speed	10-30%	10-20%	5-15%	1-5%

Table 1: Characteristics and expected uncertainties for four typical wind atlas applications

with a single homogenous surface roughness. This is the only fair way to make the comparison; otherwise, output from models handling different scales will quite surely deviate.

If feasible, both micro- and mesoscale models may be adjusted and model parameters may be changed to reflect local and regional conditions. The verification procedures further provide the necessary information for assessing the uncertainty of the modelling.

APPLICATION

Wind resource assessment for determination of wind conditions and estimation of annual energy production may be applied for many purposes, including physical planning (national, regional or local), wind farm siting, project development, wind farm layout design, micro-siting and wind farm performance verification.

The different purposes require modelling of different size geographical domains and different levels of accuracy. However, the wind atlas method described above provides opportunities to serve all these purposes; by applying the methodology with lower or higher resolution in the data and modelling. Implementation may then be planned with a successive refinement of resolution for the regions and areas of interest for wind farm development.

For wind farm siting and design, and estimation of annual energy production and wind farm efficiency, a microscale model is used to transform the regional wind climates of the wind atlas to the predicted wind climates at the turbine sites. And, a wake model is used to estimate the wind farm efficiency. Bankable estimates may be obtained where the wind farm sites are close to dedicated measurement stations.

An overview of the wind atlas approach applied for different purposes is given in Table 1.

The mesoscale numerical wind atlas in combination with an observational wind atlas offers new opportunities for doing planning on a large scale, even with limited availability of wind data from meteorological measurement stations. At wind farm sites and in project preparation, it provides a consistent basis for verification of model results against each other and against measurements and the methodology may be applied with a view to reducing uncertainties.

Evidently techniques may be improved through continued research efforts – making use of the ever increasing computing power of new computers and new measurement technologies, mapping techniques and satellite imagery. ■

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